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The Rio Madeira HVDC System – Design aspects of Bipole 1 and the connector to Acre-Rondônia

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SUMMARY

The Rio Madeira HVDC System comprises a total of 7100 MW of converter capacity required to transmit the power from the hydroelectric plants of Santo Antonio and Jirau, located on the Madeira river close to Porto Velho, to local load centres and to the main consuming areas in south-eastern Brazil. The two trunk transmission lines to the south-east are rated ± 600 kV and extend over 2350 km. This capacity is divided among two bipolar transmissions rated 3150 MW each and two back-to-back blocks of 400 MW each. ABB is responsible for the supply of the HVDC parts of Bipole 1 converters and the two back-to-back converter blocks and this paper discusses that supply.

The transmission system was auctioned under a concession process with various Lots, as is the normal practice in Brazil. This approach ensures a competitive outcome; however the overall system is owned by a number of entities, each responsible for the construction and operation of their particular Lots. As the generation facilities are similarly auctioned, a complex interface between interested parties results. This aspect is not discussed here, but has a considerable influence on the engineering solutions.

The 3150 MW, ± 600 kV, Bipole 1 employs a configuration with one converter per pole. In this project a major challenge is the very long transmission line. Additionally there is a requirement for many operating modes, including parallel operation of the two bipoles. The auctioned Lot for Bipole 1 also includes a Master Control system to coordinate joint actions involving the HVDC equipment. This Master Control is responsible for transmitted power changes by relocation of ordered power and possibly run-back in the case of loss of transmission or generation capacity. The supervision of reactive power sources is also included.

One major deviation from the system used as base for the Auction is the use of CCC (Capacitor Commutated Converter) for the back-to-back blocks. The Rio Madeira collector system feeds the very weak Acre-Rondônia 230 kV system via two back-to-back blocks, each 400 MW. In the base alternative three synchronous compensators of 100 Mvar were used, however ABB offered an alternative using CCC converters without synchronous compensators. This paper discusses the advantages of this all-static solution and shows results of dynamic simulations for this system.

KEYWORDS

HVDC, Power transmission, Rio Madeira, CCC, Capacitor Commutated Converter, weak system, harmonic filters, earth electrodes, metallic return

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1.0 - INTRODUCTION

The Rio Madeira transmission was bid under a concession process whereby the complete system is divided into various Lots and these Lots publicly auctioned as individual Transmission Concessions [1]. This approach ensures a competitive outcome, however it results in the overall system being owned by a number of entities, each of which procures its own suppliers for the equipment and services. In this paper the Portuguese word “Edital” is used to describe the set of contractual documents that form the base of the various Lots auctioned to form the complete Rio Madeira transmission system. A similar concession process is applied to the generation facilities, which results in a complex interface for administering the overall system. This aspect is not discussed here, but needs to be borne in mind when looking at the engineering challenges.

Bipole 1 is rated 3150 MW, ± 600 kV, at the rectifier and employs a configuration with one converter per pole. This configuration has been used in many projects of comparable power ratings, but is here used for first time above ± 500 kV. Experience with these similar projects gives an assurance to the performance of Bipole 1, the major difference being the very long (2350 km) transmission line. Additionally there is a requirement for many operating modes, including parallel operation with Bipole 2. While none of these modes is new, perhaps this is the first time that all of them have been required in one system. This paper describes the main technical parameters of the project, which generally follow the basic configuration of the Aneel Edital [2] without significant deviations in the case of Bipole 1.

The two back-to-back blocks of 400 MW each are used to connect the 500 kV Rio Madeira collector system (Coletora Porto Velho or CPV) to the very weak Acre-Rondônia 230 kV system, taking advantage of their asynchronous nature to ensure reliable power transfer to the load centres, including the two state capitals of Porto Velho and Rio Branco. It is in this system where the only major exception to the basic configuration of the Edital [3] was made. The basic configuration used classic converters with three 100 Mvar synchronous compensators to strengthen the Acre-Rondônia 230 kV system, whereas ABB offered a solution using Capacitor Commutated Converters (CCC) without synchronous compensators. This paper discusses the advantages of this all-static solution and shows results of dynamic simulations for this system, as well as describing the overall parameters of the CCC converters.

2.0 – THE RIO MADEIRA TRANSMISSION SYSTEM

The Brazilian system is around 95% hydroelectric and has developed over the years expanding to more remote locations. The main load centres are located in the coastal regions, especially in the southeastern state of São Paulo. By now most parts of the country are connected in a single synchronous grid, with Manaus, the capital of Amazônia, being the only major exception. However a double circuit line from Tucuruí should soon include Manaus.

The major part of the interconnected national grid system employs 500 kV, with widespread use of series compensation. There is a strong backbone connecting the North to the Central Southeast, which at the time considered in this study has three parallel 500 kV lines with a high level of series compensation. The major exception in the grid system is the Itaipu transmission, which employs both 765 kVac and ± 600 kVdc and forms the strongest single infeed, now accounting for roughly 17% of the generation capacity.

Today the states of Acre and Rondônia are connected by a very weak 230 kV system. The integration of the Rio Madeira HVDC hydroelectric plants of Santo Antonio and Jirau will change this considerably. The Rio Madeira system supplies both the local load centres and the remote consuming areas in south-eastern Brazil. To achieve this, the HVDC capacity is divided among two back-to-back blocks of 400 MW for local supply and two bipolar transmissions to the Araraquara station, each rated 3150 MW. Figure 1 shows the main features of this system [1].

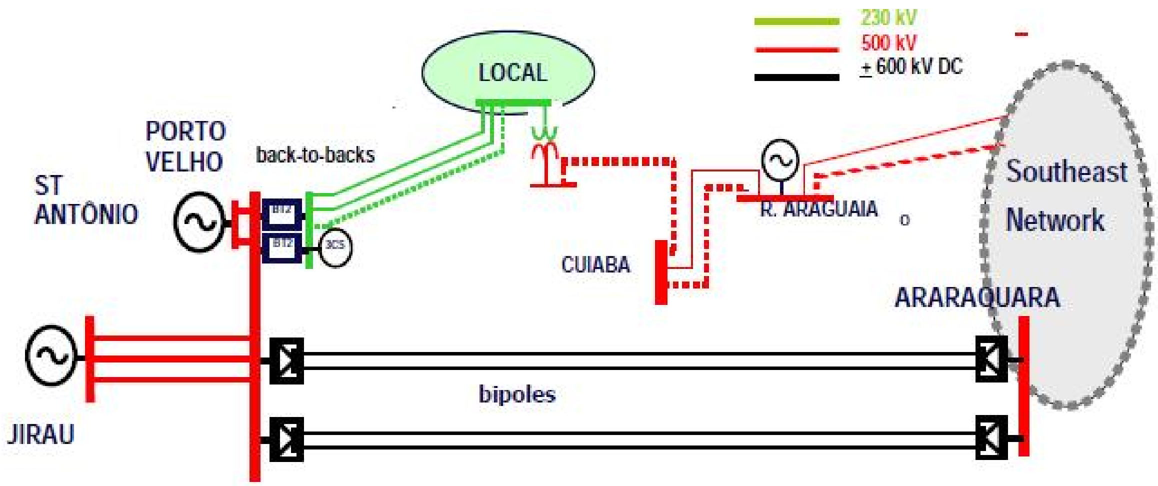

Figure 1 – The Rio Madeira Transmission System

One of the notable features of the Rio Madeira generation complex is the run-of-river design with low head turbines and very small reservoirs, not exceeding the natural flood levels of the river. However this gives the generating plants two characteristics which influence the transmission system detailed design, firstly the use of bulb turbines of small rating and with very low inertia, and secondly very large variations in seasonal power flow. It can be seen that the transmission system must take into account very large variations in the total number of machines in the isolated generating end, from a maximum of 88, or possibly more, to a minimum of perhaps twelve operating at well below rated power. Under these conditions operating criteria may be relaxed.

2.1 The ± 600 kV HVDC Rio Madeira system

The main trunk system to the interconnected 500 kV network in southeast Brazil comprises two parallel bipoles with a nominal capacity of 3150 MW and ± 600 kV from CPV to the Araraquara 500 kV substation. This part discusses the converter equipment in Bipole 1, the first of the two Lots (Lot C), see Edital Anexo 6C [2]. Also included in Lot C is the Master Control for both converter stations. Its function is to coordinate actions involving the various components installed at the converter stations. The two ± 600 kV bipolar transmission lines, each about 2350 km long and using different Rights of Way separated by a minimum of 10 km, also form part of two distinct Lots.

2.1.1 Main Circuit Design

The main circuit design follows the Edital without significant exceptions. The stations use the well accepted design with one 12-pulse converter per pole and provision for Metallic Return. As well as Metallic Return, there are many other operating configurations taking into account the two bipoles, see table 1 below and figure 2. These configurations can be combined with a range of operating modes such as reduced voltage operation, reverse power operation and various overload conditions. Additionally and not shown in table 1, there is the possibility to parallel the neutral points of the two bipoles onto a single ground electrode. All these operation configurations and modes are considered in determining the main circuit parameters, together with AC system conditions, DC line parameters, ambient conditions, manufacturing tolerances and measuring and control.

Table 1 – Operating Configurations

Configuration	Example
Normal	Each converter pole on its own line pole
Monopolar with Earth Return	P1 or P2 out of service
Monopolar with Metallic Return	Neutral of P1 on line L2
Monopolar with Earth Return and parallel lines	P1 on line poles L1 // L3
Monopolar with Metallic Return and parallel lines	P1 on line poles L1 // L3 with return on L2 // L4
Lines in Parallel	P1 on lines L1 // L3 and P2 on lines L2 // L4
Crossed Operation	Converter P1 on Line L3
Parallel Poles	Converter P1 // P3 on L1, L3 out of service
Parallel Bipoles on same line	Converter P1 // P3 on L1, P2 // P4 on L2

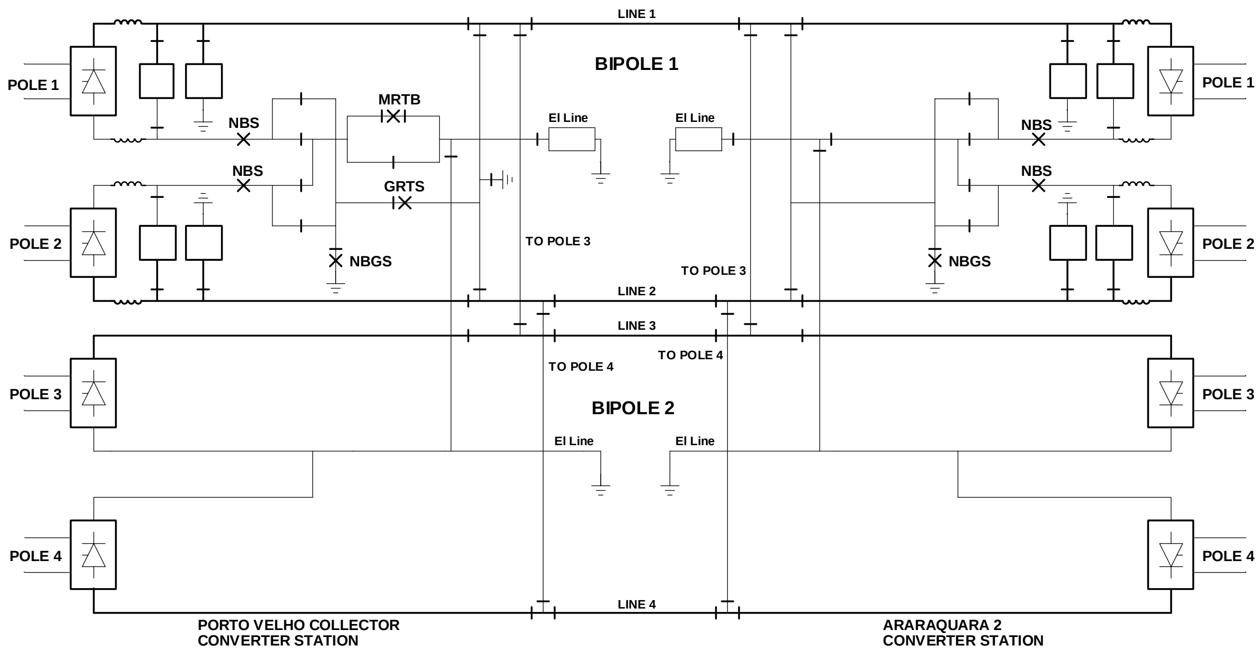

Figure 2 – The Rio Madeira ± 600 kV HVDC System

Figure 2 shows the overall connection of the two bipoles with Bipole 1 (poles P1 and P2) in more detail as is the subject of this paper. Note in the case of Bipole 1 the addition of a Neutral Bus Grounding Switch (NBGS), not included in the Edital which is discussed later.

On the 500 kV ac side, at both stations, one and a half breaker configurations are used. In Porto Velho four entries are designated for HVDC: two are for the HVDC poles and two for AC filter banks. The switching arrangement of the shunt capacitor banks and harmonic filter branches is discussed in 2.4 below.

2.1.2 Main Equipment

The design follows the Edital with one 12-pulse converter per pole, a small exception being the use of three winding transformers in CPV, as opposed to the two winding type. This is due to the use of river transport permitting the use of the larger three winding design resulting in 630 MVA single phase units. At Araraquara where road transport is required the converter transformers are of two winding design, 292 MVA per unit. This means that the valve halls are different at the two locations, quadruple valves being used at CPV, see figure 3 below, and double valves at Araraquara, all of water cooled, suspended design. The thyristors are 5” type with electrical firing, permitting the required overload characteristics of 50% for 5 seconds and 33% for30 minutes.

Air cored smoothing reactors are used, split into three units. One 15 mH unit is on the high voltage side of the converter to limit possible incoming lightning overvoltages, while the major part is in the neutral in two units each 150 mH.

Figure 2, above, shows the use of an NBGS (Neutral Bus Grounding Switch) at both stations. This device, not specified in the Edital, is included in order to increase the availability in case of loss of connection to the electrode when in bipolar operation. The NBGS closes to form a temporary connection to the station ground mat, however the bipole must be in balanced power control to ensure that the ground current is minimised.

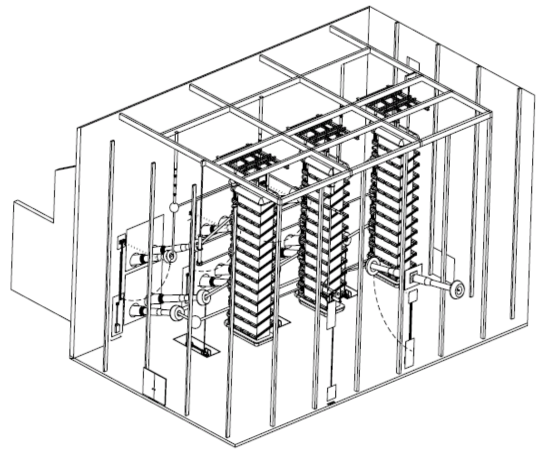

Figure 3 – One 600 kV converter at CPV

2.1.3 AC Harmonic Filters

The specified harmonic performance limits for all converter stations were defined in terms of voltage distortion levels corresponding to the national regulatory standard [4]. Regarding telephone interference criteria, no numerical limits were specified for TIF or IT, but instead a functional requirement was imposed. Typical limits were therefore assumed for design purposes and later a comprehensive inductive co-ordination study confirmed that no significant telephone interference should occur after commissioning. That functional specification and details of the inductive co-ordination study were similar to those described for dc filters in 2.1.4 below.

The harmonic impedances of the connected ac networks were not specified, but left to the suppliers to calculate. Extensive studies of the various networks, considering future configurations and contingencies, and using appropriate harmonic models of system components, were therefore made before the filter design could begin.

The ac filters are different for the two terminals of Bipole 1, and also for the two terminals of the back-to-back. The salient features of the four distinct designs are outlined below and in 2.2.2.

Bipole 1 - Araraquara 2 (500 kV)

A relatively strong receptor system and reasonably well-damped ac network harmonic impedance permitted the use of broad-band damped HP12/24 filters. Four such units of 305 Mvar each, plus 3 shunt capacitor banks of similar size constitute the reactive compensation. A cross-modulation study proved that there was no need for lower order filtering.

Bipole 1 – Coletora Porto Velho (500 kV)

The ac network at the rectifier end of the transmission consists only of the generators and connecting lines and, with no local load, has very little damping. The number of generators can vary over a wide range, with numerous connection configurations, giving a wide range of possible network harmonic impedance. Low-order filtering is required to prevent possible resonances involving the interaction between ac and dc sides. With few connected generators, the ac system can present a very low SCR, and so these low-order filters are required even at low dc power operation. This adds to the problem of avoiding possible self-excitation of generators due to the connection of excessive filter capacitance – particularly when considering the parallel operation of the two Bipoles and the back-to-back on the same 500 kV bus, each with its own low-order filtering. Considering also that the specified harmonic distortion limits were low for such an islanded system, the filters had to be highly efficient in their use of connected capacitance, and sharply tuned branches are required at a number of frequencies. The complete design consists of:

- three sub-banks, each of 263 Mvar, configured as a HP 2/3 plus a HP 12/24 branch
- two sub-banks, each of 263 Mvar, configured as a HP 5/36 plus a HP 12 branch
- one sub-bank of 183 Mvar, configured as a HP12

Consideration of Bipole 2

In the design of the ac filters for both Araraquara and Coletora Porto Velho 500 kV (Lot A and Lot C), consideration had to be given to the parallel connection of Bipole 2 and its filters on the same bus. Bipole 2 belongs to a different concessionaire and is supplied by a different HVDC manufacturer, and is also programmed one year later, but potential coordination difficulties were resolved. At Araraquara a common filter design was agreed, but at Porto Velho the Bipole 2 filter design used a completely different configuration, with triple-tuned branches, nevertheless presenting an approximately similar overall impedance profile, albeit with higher q-factors. As performance criteria were specified independently for each Lot, the joint performance was not a contractual issue; however it was important to rate the Bipole 1 and back-to-back 500 kV filters with consideration to harmonic interaction with Bipole 2.

2.1.4 DC Harmonic Filters

The main objective of dc filters is to prevent telephone interference, and technical specifications normally define a limit on the "equivalent disturbing current, I_{eq}", which is a weighted vectorial sum of the harmonic currents in all the dc line conductors. For the Rio Madeira bipoles no such numerical limit was specified, but instead a functional requirement that the dc filters should "not permit the dc side harmonics to produce interference in telephone lines in service at the date of the HVDC commissioning above the limits of the corresponding standards." Thus the onus to determine a suitable limit for I_{eq} fell on the suppliers. Due to the short time available, design target limits were selected by the supplier based on previous experience, namely 1500 mA for bipolar operation and 2200 mA for monopolar modes.

The design of the dc filters was heavily influenced by the location of the smoothing reactors on the neutral side of the converters. This choice has little impact on the characteristic harmonics, but greatly affects the path of triplen harmonics flowing to ground through the stray capacitances of the converter transformers. The mitigation normally provided by the neutral bus capacitor becomes relatively ineffective, and a significant amount of higher order triplen harmonics tend to follow a return path through the dc line capacitance to ground. In order to provide a low impedance in-station bypass for these harmonics, the dc filters include low-impedance filtering covering a range of higher-order triplens, nominally tuned to around the 50th harmonic.

The dc filters are identical at both converter stations and consist of two separately switchable harmonic filter branches per pole – a 6/12/50 harmonic branch pole-neutral and a single-tuned 50th harmonic branch to ground, each of 0.7µF. The 6/12/50 is a well-damped filter designed to mitigate 12th harmonic and a wide range of higher frequencies, and also to restrict the 6th harmonic (mainly due to ac side 5th and 7th) in monopolar configurations. The high frequency tuning is included to provide some redundancy if the ST50 branch is out of service. For the HP6/12/50 branch the path to ground for high order triplens is not direct, but through the neutral bus capacitor, which is not quite as effective but is preferable for insulation co-ordination of the low voltage filter components.

In parallel with the design phase of the project, a highly comprehensive inductive co-ordination study was conducted in order to confirm the validity of the chosen I_{eq} limits and to identify any particular areas where mitigation measures might still be needed on the telephone systems. Using data from the regulator ANATEL and online mapping, the route of every possible vulnerable telephone line along the 2350 km dc line route and the electrode line routes was estimated. Considering a range of assumptions regarding the likely shielding and balance of those lines, and the earth resistivity, the resulting interference levels were calculated corresponding to the maximum assumed I_{eq} limits used for the filter design. The results confirmed that no significant telephone interference should occur, thereby validating the chosen design limits for I_{eq}.

2.1.5 Ground Electrodes

Resistivity surveys were carried out at the two locations, including deep magnetotelluric measurements. Following this bore holes were used to take core samples before confirming location and final design. At both locations vertical sub-electrodes are used due to difficulties found. In the Porto Velho region the difficulties come from an underlying rock formation covered with alluvial sandy soil. The dry surface, as well as the deep rock, has a very high resistivity. This has led to the use of vertical sub-electrodes, each about 80 m deep isolating the first 10 m of high resistivity soil. The arrangement is in a ring 1000 m diameter. In Araraquara the resistivity is lower, but a rock formation is close to the surface. This also led to the use of vertical sub-electrodes, in this case of varying depths of 20 m to 40 m according to the proximity to the rock layer. The arrangement follows the perimeter of the land acquired for this purpose, but approximates to a rectangle of about 800 m by 500 m.

In both cases the distance required to find a suitable site was well above the minimum of 15 km specified in the Edital. At Porto Velho the electrode is located about 70 km from the bipole and at Araraquara 30 km.

2.2 The Back-to-back system to Acre-Rondônia

Figure 1 also shows the back-to-back connection to Porto Velho at 230 kV, where it ties to the existing Acre-Rondônia system. This 230 kV system is very weak, running for about 1000 km to near Cuiaba where it joins a 500 kV radial system that then connects to the main south-east system about another 900 km beyond.

The two back-to-back blocks are each rated 400 MW, although maximum power transmission into the 230kV is limited to 600 MW, at least until 2017, due to the weakness of the system. To overcome the problems of feeding into such a weak system, the back-to-back uses Capacitor Commutated Converters (CCC), improving not only performance related to commutation failures, but also reducing the need for shunt reactive compensation [4]. Although not strictly necessary from a performance point of view the 500 kV side of the back-to-back also uses CCC technology. This permits use of harmonic filters with a relatively low Mvar rating on both sides of these converters. Note that due to the requirements of the Grid Procedures for connection of reactive compensation, these harmonic filters are connected to the 500 kV and 230 kV bus-bars separately from the converters.

The design follows the CCC principle with series capacitors connected between the transformers and the valves. A higher value of capacitance is used on the 230 kV side in order to provide the reactive support necessary. Three phase, nine winding transformers are used and were transported by river. The valve halls contain a single octal valve structure for each phase, again water cooled and suspended design.

2.2.1 Operating modes

The back-to-back has to operate in various considerably different configurations of the network:

A. Feeding weak 230 kV network synchronous with the Brazilian network.
B. As A, but with a large gas fired thermal unit in operation locally in Porto Velho.
C. As A initially, but separating from the Brazilian System (Isolated operation).
D. Start-up in isolated operation (Black start).
E. Feeding 500 kV converter bus from 230 kV (Reverse power direction).

These five possibilities cover a wide range of network characteristics and each is discussed here.

A. Weak 230 kV system

This is considered the normal mode of operation and is characterised by the very low short circuit level on the 230 kV side connected to the Acre-Rondônia network which is characterised by long lines and wide variation in loadings. The impedance of the network seen by the converter is influenced by variations in shunt compensation and the number of generators connected at the Samuel power plant.

The Samuel 250 MW hydro power plant is close to the converters, connected by about 70 km of 230 kV line. Each generator unit is only 50 MVA and there is a strong influence of these machines on the short circuit power. This also affects the dispatch conditions, as during the rainy season Samuel also loads the 230kV system. However during the dry season one machine in operation is most likely.

Having one machine in operation the ESCR is 0.340 and with five machines in operation the ESCR is 0.995. The value of 600 MW is defined as the maximum operating capacity of the back-to-back transmission system, at least until 2017 which was the horizon year used in the electrical-mechanical stability studies of the Acre-Rondônia network [1] prior to issue of the Edital.

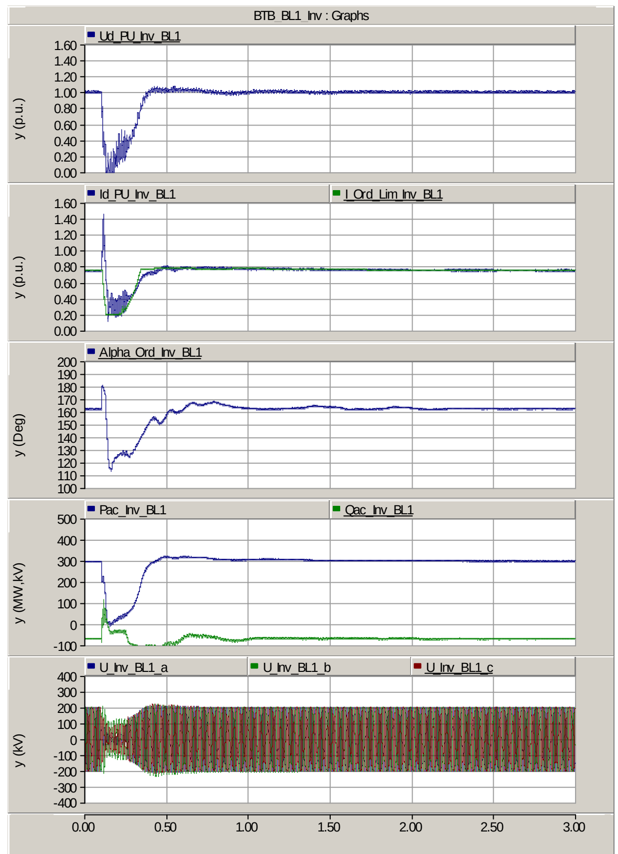

Figure 4 – Single phase fault, configuration A

In order to obtain satisfactory performance not only is CCC technology used, but also a special control strategy is applied. This combination allows the elimination of the additional active voltage support in Porto Velho, e.g. Synchronous Condensers or Static Var Compensators. The main control strategy consists of using the CCC inverters to control the 230 kV bus voltage, rather than the classic current control used in most HVDC links. Additionally there is stabilization of Acre-Rondônia network by frequency control on Porto Velho 230 kV side (this control is permanently active), with an integral part (includes a dead-band of ±0.6 Hz) and a proportional part that is permanently active. Figure 4, above, shows a single-phase fault at Coletora Porto Velho 230 kV on one transmission line to Porto Velho with the back-to-back dispatched at 600 MW (300 MW each) and one machine at Samuel.

B. Strong 230 kV system

The 230 kV system around Porto Velho contains thermal generation, including one 345 MW gas turbine-based combined cycle plant. Should this plant be dispatched due to low hydraulic capacity in the region, then the short circuit level in the 230 kV system is considerably increased. The controls are optimised for Scenario A; however satisfactory performance is also achieved under Scenario B with a much stronger system.

C. Isolated 230 kV system

In case of opening of the 230 kV interconnection to the main Brazilian grid, the frequency control mentioned in 2.2.1 above comes into action. The back-to-back is the main source of controllable power in maintaining the frequency of the system close to the nominal value. Employment of this Frequency Control means that when the Acre-Rondônia network becomes isolated from the main grid, the operating frequency may deviate from nominal value by 1% due to the dead-band of ±0.6 Hz.

E. Black start

'Black Start' of the back-to-back converters is has the intention is to be able to supply the capital cities of Porto Velho and later Rio Branco after a black-out in the Acre-Rondônia 230 kV system. Perhaps it is better called "Grey Start" as some help is needed from the Samuel hydro plant. In addition to two machines in Samuel, both blocks of the back-to-back are required in Bi-Block power control. Following this, the operator manually selects the "Isolated Mode" and then starts the back-to-back. The study has shown that after having initiated the back-to-back in 'Black Start' mode it is possible to supply all the loads in Porto Velho. It has also shown that loads in Rio Branco can also be supplied after having energized the transmission lines between Porto Velho and Rio Branco.

F. Reverse power direction

The back-to-back transmission system is also prepared to operate in reverse power direction, assuming that electrical power is available in the Acre-Rondônia network to be transmitted to the CPV 500 kV system. Under this special operating condition it has been assumed that the thermal units in Porto Velho would be in operation and that the power produced by these thermal units would be delivered to Araraquara via the back-to-back and the HVDC Bipoles.

2.2.2 AC Harmonic Filters for the Back-to-Back

<u>Back-to-Back – Coletora Porto Velho (500 kV)</u>
The back-to-back shares a common 500 kV bus with Bipole 1, but because the two transmissions are owned by different concessionaires, it was necessary for contractual and regulatory reasons to provide distinct filters for each Lot, with separate redundancy, rather than to design the most efficient common filtering solution. Being a CCC, the back-to-back requires relatively little shunt reactive compensation and so its filtering was designed to make an efficient use of as little capacitance as possible. Importantly, the overall impedance characteristic has a reasonably similar profile to that of the Bipole filters, ensuring acceptable per-unit sharing of harmonic loading between the two sets of filters. The design consists of three sub-banks (one of which is redundant), each of 142 Mvar and each configured as a HP3/5 plus a triple-tuned HP 12/24/36.

<u>Back-to-Back – Coletora Porto Velho (230 kV)</u>
Again, the CCC concept motivated the use of small but efficient filters. The design consists of 4 banks, 59 Mvar each, subdivided into a total of 8 sub-banks. The sub-banks are configured as:

- 4 sub-banks of 11/13
- 2 sub-banks of HP 24/36
- 1 sub-bank "C-type" HP 3
- 1 sub-bank with a switchable low voltage section to form either a HP 24/36 or a "C-type"HP3, for use as a redundant element.

Shunt reactors (63 Mvar each) are also included two of the banks, to limit reactive exchange with the very weak 230 kV network.

2.3 The Master Control system

The Master Control is specified in the Edital as part of the Lot for the Bipole 1 converters. However its function is to coordinate various actions involving components from all Lots installed at the two converter stations, including converters, harmonic filters, reactive compensation, generators and outgoing lines. In addition to coordination, Master Control acts as a protection to avoid dangerous operating configurations, especially regarding overvoltages and self-excitation.

The main tasks for the HVDC Master Control System are to:

i. Re-distribute the active power between Bipole 1 and Bipole 2 in an optimal fashion upon loss or limitation of HVDC transmission capacity below the transmitted power level in any of the poles or bipoles. Active power is also re-distributed from the back-to-back to poles in operation upon reduction of the back to back transmitted power level due to loss or limitation of the back to back. This also may involve tripping of generators to avoid overspeed, limited to 66 Hz by the Grid Procedures. Note that where possible the power transmission on the back-to-back is kept constant due to the weakness of the 230 kV system.
ii. Balance the active power on the CPV 500 kV bus with the total amount of generated power in Santo Antonio and Jirau. This means ordering a so called “Runback” of the power transmitted in Bipole 1 and Bipole 2 in case of loss of generation or collector transmission capacity. For similar reasons a Runback can also be ordered due to limitations in the amount of active power that can be received in Araraquara as a result of the network topology.
iii. Avoid self excitation of the generators in Jirau and Santo Antonio by limiting the maximum amount of shunt reactive connected to the 500kV busbars according to number of machines and network configuration.
iv. Reduce potential overvoltages on the 500 kV networks by disconnecting or inhibiting connection of shunt capacitors or filters.
v. Balance and control the reactive power exchange between the HVDC converter stations and the corresponding network by operating the shunt capacitors or filters, while obeying the minimum filtering requirements of each bipole or back-to-back.
vi. Validate the Operating Configurations when sharing equipment between the two Bipoles. This is to cover such operating configurations as paralleling converter poles, sharing an electrode, crossed operation and such status signals that are required to be exchanged between bipoles. Note that not all signals between bipoles go via Master Control as protective actions and current control in parallel operation require very fast direct communication.

3.0 – PRESENT STATUS

At the time of writing the basic project design is approved, equipment has been manufactured and is at site, under erection or in transport. Commissioning is to take place during 2012.

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